EFFECT OF FRUIT REMOVAL ON CARBOHYDRATE CONCENTRATIONS OF CANTALOUPE (*Cucumis melo* L.) ROOTS IN NATURALLY INFESTED SOIL WITH *Monosporascus cannonballus*

A Thesis

by

JANG HOON LEE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Plant Pathology

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Approved as to style and content by:

James L. Starr (Co-Chair of Committee)	Marvin E. Miller (Co-Chair of Committee)
Kevin Crosby (Member)	Dennis C. Gross (Head of Department)

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ABSTRACT

Effect of Fruit Removal on Carbohydrate Concentrations of Cantaloupe (*Cucumis melo* L.) Roots in Naturally Infested Soil with *Monosporascus cannonballus.*

(December 2003)

Jang Hoon Lee, B.S., Chonnam National University

Co-Chairs of Advisory Committee: Dr. James L. Starr
Dr. Marvin E. Miller

The effect of fruit removal from cantaloupe was studied under field conditions in a soil naturally infested with *Monosporascus cannonballus*. Fruit removal resulted in greater sugar accumulation in the cantaloupe roots compared to the roots from plants on which the fruits were allowed to develop normally. Individual, total, and combined root carbohydrate levels were greater in plants without fruit than in plants with fruit. Five major sugars (stachyose, raffinose, sucrose, glucose, and fructose) were found in the cantaloupe roots. Stachyose concentrations were higher than all the other sugars in the cantaloupe roots. Disease severity on the cantaloupe roots with fruit removed was less severe than on roots of plants with fruit, and dry weights were higher in the fruit removal treatment than those of the fruit non-removal treatment.

Fruit removal results in increased root growth and carbohydrate accumulation in the cantaloupe roots. Root sugar concentrations affected infection efficiency and disease progress of Monosporascus root rot and vine decline. Therefore, the retarded development of Monosporascus root rot and vine decline is associated with a greater carbohydrate accumulation in the cantaloupe root.

DEDICATION

I dedicate my thesis to my mother and father because their love and support have made my thesis possible.

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I would like to thank my committee member, Dr. Kevin Crosby, for his support and valuable time. I would also like to thank my co-advisor, Dr. Marvin Miller, for providing me with funding and for his wonderful support. I would like to acknowledge my co-advisor, Dr. James Starr, for taking me on at the last minute and giving thoughtful advice.

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I would like to extend another thanks to Suzanne Segner for being a wonderful boss. Working for her was an absolute pleasure.

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TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

FIGURE Page

LIST OF TABLES

TABLE Page

CHAPTER I

INTRODUCTION

Monosporascus root rot and vine decline in cantaloupe, caused by *Monosporascus cannonballus*, reduces economic yields in the Lower Rio Grande Valley of Texas. This disease is prevalent also in California, New Mexico, Arizona, along with south Texas, due to the high temperatures in these areas and their alkaline soils (22). Previous research on Monosporascus root rot and vine decline included identification of resistant varieties (Wolf, unpublished data, 40), effective fungicides (6, 22, 24), and cultural practices (6) that minimize disease occurrence. Symptoms of this disease include wilting and sudden death above ground 2 to 3 weeks before harvest without previous disease identification (22). Control of this disease is difficult due to the late expression of symptoms. Further, this fungus only infects roots, so that incidence of the disease is masked (22). In naturally infested soils, ascospores of *M. cannonballus* initiate infection of plants with no visible symptoms until 2 to 3 weeks after planting (22, 34)

M. cannonballus causes wilting of cantaloupe due to damage of roots by

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This thesis follows the style and format of Phytopathology.

tylose formation of root vessels. Tylose formation in roots causes leaf and stem wilting and sudden death by restricting of the water flow (1).Although tylose formation affects wilting of the cantaloupe plants, the major cause of wilting and sudden death is severe root rot (Miller, personal communication), and tylose formation was not the major reason leading to Monosporascus root rot and vine decline (28). Normally, this wilting and collapse is expressed during fruit maturation. Thus, fruit size and fruit quality are affected by this disease, although no visible above ground symptoms occur prior to harvest. It is believed that fruit set and maturation affect disease progress in cantaloupe plants infected with *M. cannonballus.*

Monosporascus root rot and vine decline disease was first noticed in south Texas following the appearance of new hybrid cultivars and alteration of cultural practices (3). The fruits of new hybrid cultivars are earlier to mature and have fruit of larger size than those of old cultivars. Monosporascus root rot and vine decline was not recognized as a destructive disease before the appearance of new hybrid cultivars with these traits. Cantaloupe plants have a high water demand due to their high shoot/root ratio (30), therefore the new hybrid cultivars may affect water stress on the cantaloupe roots. Thus, disease due to Monosporascus root rot and vine decline is more severe in plants with greater fruit set (3). When fruits are present on cucumber, root dry weights are reduced with increasing numbers of fruits (20). Stigter (35) also reported that fruit set suppressed root growth in cucumber and that root growth resumed after harvesting fruits. This observation indicates that fruit set inhibits root growth in cucumber, and development of fruits caused physiological root death (37). Similarly, cantaloupe root growth also might be retarded by fruit set and maturation. Change of cultural practices also affected Monosporascus root rot and vine decline. Drip irrigation, transplanting and lower plant density suppressed root growth of the cantaloupe plants, and mulching provided optimum environmental conditions to the pathogen (3,17). These conditions caused poor root systems and promoted frequent occurrence of Monosporascus root rot and vine decline.

Vine declines and root rots in the cantaloupe are caused by various pathogens, and two major groups of vine decline are known (3). The vascular pathogens *Fusarium oxysporum* and *Verticillium dahliae* cause wilt disease by blocking xylem in plants. Vine declines due to crown rot fungi such as *Didymella bryoniae* and *Macrophomina phaseolina* typically occur during early stages of the plant growth and infect crown lesions of cantaloupe.

Although fruit load appears to be directly correlated with Monosporascus root rot and vine decline, this relationship has not been rigorously tested. Removal of fruit from infected plants has been shown to prevent wilting and vine collapse (Wolf, unpublished data, 28). Several studies have reported that fruit removal increases vegetative growth of the plants (11, 28, 35), and fresh root weights and sugar concentrations in roots of cotton (8). In a recent study, fruit removal from cantaloupe increased root growth and decreased disease severity compared to plants whose fruit were not removed (28). Thus, there appears to be a relationship between fruit load and disease severity. Removal of fruits increased total number of leaves, total dry matter mass, and root sizes in cantaloupe (9), indicating that fruit removal might increase availability of photosynthates in the plant. It is possible that fruit removal makes the roots and the plants stronger and hardier than plants whose fruit were not removed. Thus, fruit removal roots may inhibit the pathogen and increase tolerance to environmental stress.

Pharr et al. (27) reported that fruit growth was highly competitive with vegetative growth in the cucumber plants because fruits are the strong sink at fruit maturation period. Vlugt (37) suggested that physiological root death is caused by competition for assimilates between roots and fruits. Root growth is related to net assimilation rates and more than 80% assimilates moved to the fruit (36). Considering this situation, fruit removal may increase carbohydrate concentrations in vegetative organs such as roots. If more carbohydrates accumulate in the cantaloupe roots, the root system has an energy source and may suppress disease development. Conversely, if a cantaloupe plant has a poor root system due to environmental stress or biotic agents, carbohydrate concentrations may decrease in the roots. If fruit removal increases carbohydrate concentrations in the cantaloupe roots compared to plants that retain their fruit, root size (area and dry weight) may increase and disease severity may be reduced. Thus, high levels of carbohydrate accumulation in the cantaloupe roots may result in healthier cantaloupe root systems. Healthier roots may reduce disease severity of Monosporacus root rot and vine decline.

The objective of this study was to determine the relationship of carbohydrate concentrations in roots of cantaloupe plants with and without fruit and the development of Monosporacus root rot and vine decline. Comparisons were made of the carbohydrate concentrations in the roots of plants with and without the fruits. Analysis of carbohydrates in the roots of plants grown at different maturity stages was done by using high performance liquid chromatography (HPLC).

CHAPTER II

MATERIALS AND METHODS

Variety of cantaloupe. Copa de Oro, which is susceptible to *M. cannonballus,* was used for the experiments.

Planting dates. The cantaloupe seeds were directly planted on April 21st 2002 and March 19th 2003.

Field conditions. The soil (a sandy clay loam soil), at Texas Agricultural Experiment Station in Weslaco, TX, was naturally infested with *M. cannonballus*. Field plots (12) were three rows, 90 m long X 2 m wide. Plants were grown 30 cm apart. Drip irrigation and black mulch were used in accordance with local production practices. Plants in 6 plots were allowed to flower and produce fruit. Female flowers were removed from plants in 6 other plots. A completely randomized design was used.

Collection of root samples. In 2002, root samples (1 plant/replication) were taken 4, 6, 8, 10, and 12 weeks after planting date (APD), and in 2003, root samples (2 plants/replication) were taken 1, 3, 5, 7, and 9 weeks after appearance of female flowers. Roots were collected from 33,750 cm^3 (30 cm X 45 cm X 25 cm) soil in such a manner so as to minimize loss of the root system. The roots were collected from below the crown and all the roots were placed immediately in an insulated box with ice. The roots were washed in an ice bath, and fresh root samples were weighed. All root samples were stored at –80^{o}C over night. Samples, which were stored at –80^{o}C, were lyophilized, and dry weights were measured. Dried samples were ground with a grinder and passed through a #20 mesh sieve (864 µm), and the powder stored in desiccators at -20^{o}C.

Measuring disease severity. A quantitative measure of disease severity was used with a scale 1 to 5; 1 = no disease, 2 = root rot in secondary roots, 3 = root rot in main root and few perithecia present on the roots, 4 = perithecia present in secondary roots, and 5 = severe root rot and perithecia present abundantly.

Identification of diseased roots. Root samples from each plant were surface sterilized for 1 minute in 0.5% NaOCl and rinsed in sterile water. Six segments of each root sample were plated on water agar. Mycelia growing on the agar after 3 to 4 days were transferred to V8 agar. Identification of *M. cannonballus* was confirmed after one month based on presence, size, and shape of perithecia (29).

Root carbohydrates extraction. The extraction procedure followed was that of G. Lester (USDA, ARS, Weslaco) (personal communication). Carbohydrates were extracted from 0.5 g of ground lyophilized tissue in 50 mL centrifuge tubes with 10 mL of 80% ethanol at 80 to 85^{o}C. Samples were mixed well with a Polytron (Kinematica, Switzerland) for 1 minute at room temperature, and then samples were filtered through Whatman #1 filter paper. The centrifuge tubes were rinsed with 5 mL of 80% ethanol at 80 to 85^{o}C and added to the root residue on filter paper, and 5 mL of filtrate was collected in a reaction vessel. Five mL of filtrate was evaporated to 0.2 mL under N_2 at 40^{o}C using a reactitherm and brought to 1.0 mL with deionized water (Milli-Q water; Millipore Corp., Medford, MA). Samples were filtered through a Waters C18 SepPac cartridge, previously rinsed with 2 mL deionized water. Filtrates were stored at -20^{o}C.

Carbohydrate analysis. All samples were analyzed using the HPLC carbohydrate procedure of G. Lester (Personal communication). Root samples were diluted to 5.0 mL (samples of 1 week were diluted to 2.0 mL), and 30 µL was injected into Rheodyne 7126, 20 µL fixed loop injector.

HPLC condition. A Milton Roy ConstaMetric III pump (Milton Roy, Ivyland, PA) was used at a flow rate of 0.5 mL/minute and a mobile phase of de-gassed deionized water. A Bio Rad HPLC carbohydrate Analysis Column Aminex HPX-87C 30cm * 7.8mm (Bio Rad, Hercules, CA) at 80^{o}C was used. Carbohydrates were separated using an Aminex HPX-87C guard column (Bio Rad, Hercules, CA). The carbohydrates were detected using a HP 1047A refractive index detector (Hewlett-Packard, Avondale, PA). The detector was maintained at 40^{o}C at a range setting of 2. Carbohydrate peaks areas were recorded using a HP3396 series II integrator (Hewlett-Packard, Avondale, PA) with the following settings; attention: 2*6, area rejection: 50000, peak width: 0.04, chart speed: 0.2cm/minute, threshold: 5, and peak capacity: 1244.

Melon root carbohydrates. Melon root carbohydrates were compared to known standards of 1mg/mL of stachyose, raffinose, sucrose, galactinol, glucose, fructose, sorbitol, galactitol, myo-inositol, and galactose. Concentrations of each carbohydrate were determined by the following formula.

mg root sugar/ g dry weight =

$$\frac{\text{(Area of root sugar)}}{\text{(Area of standard)}} \times \frac{\text{(mg standard)}}{\text{(mL)}} \times \frac{\text{(15mL EtoH X Concentration volume X Dilution volume)}}{\text{(g dry weight)}}$$

Area of root sugar = Area amount of each sugar; Area of standard = Area amount of each respective sugar; mg standard/mL = Concentration of each respective standard sugar; g dry weight = 0.5 g (dry weight of cantaloupe root used for extraction); Dilution volume = 2 and 5 (In 2002 trial, 1 week sample is 2, 1 mL root filtrate : 1 mL deionized water, and 3, 5, 7, and 9 week sample are 5, 1 mL root filtrate : 4 mL deionized water. In 2002 trail, all samples are 5.); Concentration volume = 1/5 (5mL filtrate was evaporated to 0.2 mL and brought up 1 mL).

Data analysis. The data was subjected to analysis of variance, and means were compared by Duncan's multiple rage tests using SAS (SAS Institute, Cary, NC).

CHAPTER III

RESULTS

Disease severity in 2003 trial. Regardless of fruit removal treatment, disease severity on cantaloupe roots increased continuously from 1 week after anthesis (AA) until 9 weeks AA. Few root rot lesions were observed at 1 week AA, but increased from fruit set until crop maturity. Perithecia of *M. cannonballus* were present on root surfaces of plants with fruit at 7 weeks AA, and they were abundant on roots toward the later stages of fruit development (Fig. 1). However, disease severity was less severe on roots of plants from which fruit was removed than those that retained their fruit (Fig. 2). At 7 and 9 weeks AA, the majority of the cantaloupe roots were severely infected with *M. cannonballus*, and numerous perithecia were found on roots of plants with fruit. For both treatments, disease severity was the greatest at 9 weeks AA. Disease severity was different among dates, and between treatments ($P < 0.0001$) (Table 1).

Table 1. Analysis of variance for effect of fruit removal on disease severity, root fresh weights and dry weights (2003).

Source of data	DF	Disease severity			Fresh weights			Dry weights		
		MS	F	P	MS	F	P	MS	F	P
Date(D)	4	20.15	366.40	<.0001	2654.08	142.11	<.0001	35.57	131.67	<.0001
Treat(T)	1	3.26	59.39	<.0001	1238.42	66.31	<.0001	16.33	60.48	<.0001
D*T	4	0.40	7.31	0.0001	307.95	16.49	<.0001	4.35	16.11	<.0001

Fig. 1. Perithecia (arrows) present on cantaloupe root surfaces in non-removal treatment at 7 weeks AA (2003).

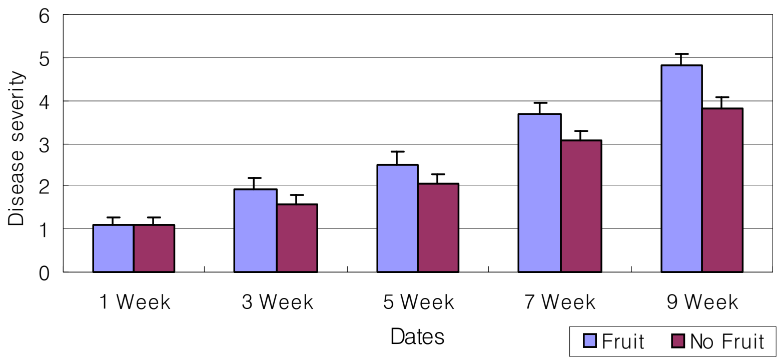

Fig. 2. Disease severity (2003) on the cantaloupe roots infected with *M. cannonballus*. A quantitative measure of disease severity was used a scale 1 to 5; 1 = No disease, 2 = root rot in secondary roots, 3 = root rot in main root and few perithecia present on roots, 4 = perithecia present in secondary roots, and 5 = severe root rot and perithecia present abundantly. Mean values represent six replications. Bars indicate mean standard error.

Root fresh and dry weights in 2003 trial. Root fresh and dry weights of the cantaloupe increased with time, regardless of treatment (Fig. 3 and 4). There were significant differences in root fresh and dry weights between plants with and without fruit (Table 1). Also, there were significant differences among the dates (Table 1). After 9 weeks AA, the maximum root fresh and dry weights were 43.9 g and 5.24 g, respectively, for plants without fruit, and at 7 and 9 weeks AA, root dry weights were identical for the two treatments (Fig. 3 and 4). At 9 weeks AA, fresh and dry weights of plants with fruit decreased because of severe root rot. Although perithecia were present on roots in the fruit removal treatment at 9 weeks AA, the fresh and dry weights increased (Fig. 3 and 4).

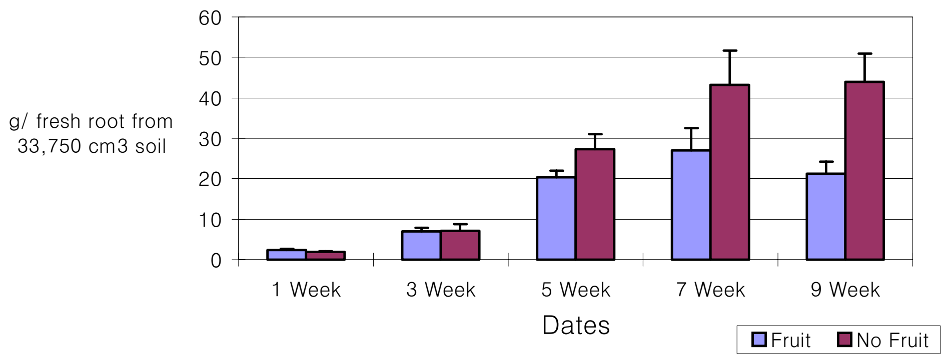

Fig. 3. Effect of fruit removal on fresh weights of cantaloupe roots at 1 to 9 weeks AA (2003). Values are means of six replications with standard error indicated.

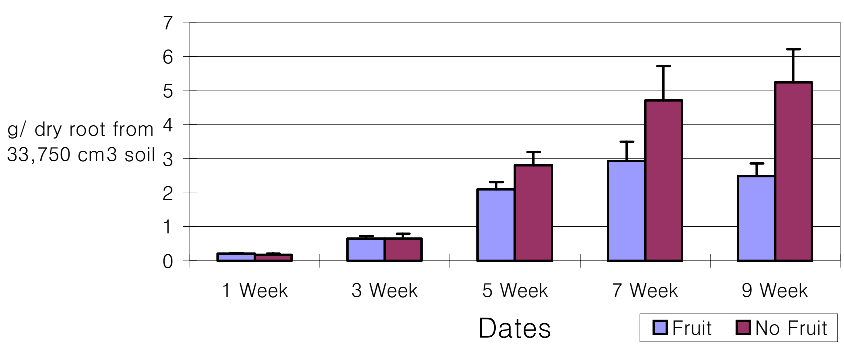

Fig. 4. Effect of fruit removal on dry weights of cantaloupe roots at 1 to 9 weeks AA (2003). Values are means of six replications with standard error indicated.

Carbohydrate concentration in cantaloupe roots in 2003 trial. Five major sugars, including stachyose, raffinose, sucrose, glucose, and fructose were found in the cantaloupe roots. A very small amount of galactinol and one unknown sugar were found in the cantaloupe roots. Galactinol was less than 1 % of the total sugars (Data not shown). Root sugar levels were higher in plants without fruit than plants with fruit and significantly different among the dates and between the treatments (Table 2). Root sugar levels peaked at 3 weeks AA and decreased toward later stages of fruit development, regardless of treatment. Sucrose concentrations, however, peaked at 3 weeks AA and again at 7 weeks AA in the fruit removal treatment (Fig. 5).

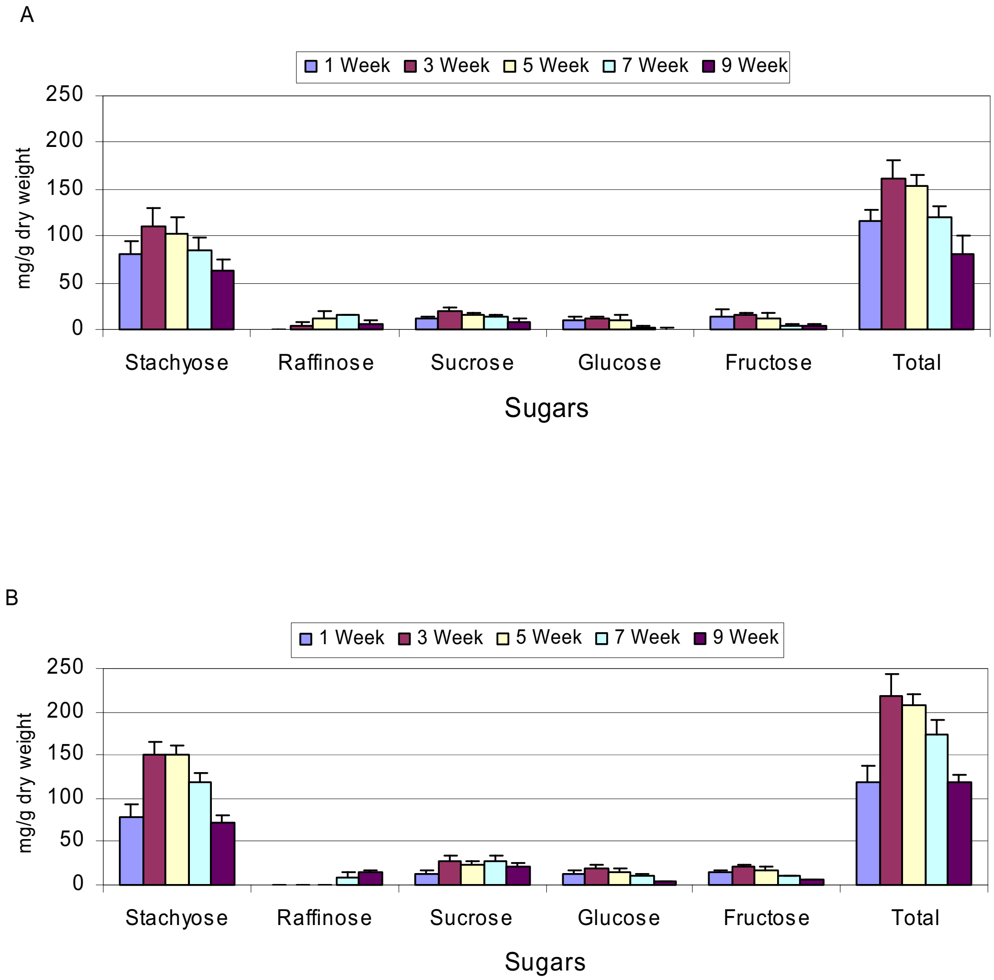

Fig. 5. Carbohydrate concentrations in roots of cantaloupe with fruit A) and fruit removed B) at 1 week AA through 9 weeks AA (2003). Values are means of six replications represent. Bars indicate standard error.

Table 2. Analysis of variance for effect of fruit removal on individual, total, and combined carbohydrate concentrations in cantaloupe roots (2003).

Source		Stachyose			Raffinose			Sucrose			Glucose			Fructose		
of data	DF	MS	F	P	MS	F	P	MS	F	P	MS	F	P	MS	F	P
Date(D)	4	9174.4	49.98	<.0001	310.98	17.09	<.0001	282.43	19.62	<.0001	321.13	28.24	<.0001	392.38	35.84	<.0001
Treat(T)	1	10272	55.96	<.0001	90.35	4.96	0.0304	1069.77	74.32	<.0001	390.3	34.32	<.0001	192.17	17.55	0.0001
D*T	4	1313.6	7.16	0.0001	188.81	10.37	<.0001	93.23	6.48	0.0003	10.82	0.95	0.4418	14.9	1.36	0.2606

Source		Total carbohydrates			Glucose+Fructose			Sucrose+Glucose+Fructose			Stachyose+Raffinose+Sucrose			Stachyose+Raffinose		
of data	DF	MS	F	P	MS	F	P	MS	F	P	MS	F	P	MS	F	P
Date(D)	4	17701.8	62.95	<.0001	1414.4	35.84	<.0001	2099.14	26.76	<.0001	11725.29	58.81	<.0001	8598.1	55	<.0001
Treat(T)	1	25017.8	88.96	<.0001	1130.2	28.64	<.0001	4399.15	56.09	<.0001	15513.01	77.81	<.0001	8435.3	53.96	<.0001
D*T	4	1571.65	5.59	0.0008	50.35	1.28	0.292	236.3	3.01	0.0265	1086.95	5.45	0.001	732.43	4.68	0.0027

Stachyose. Stachyose levels in the cantaloupe roots, regardless of treatments, peaked at 3 weeks AA, and then decreased (Fig. 6). There were significant differences in stachyose concentrations among the dates and between the fruit removal treatments (Table 2). Stachyose levels were the highest among sugars regardless of treatment (Fig. 6). Stachyose was 66 - 79% of total sugars in roots of plants with fruit and 61 - 74% of total sugars in plants without fruit (Fig. 6).

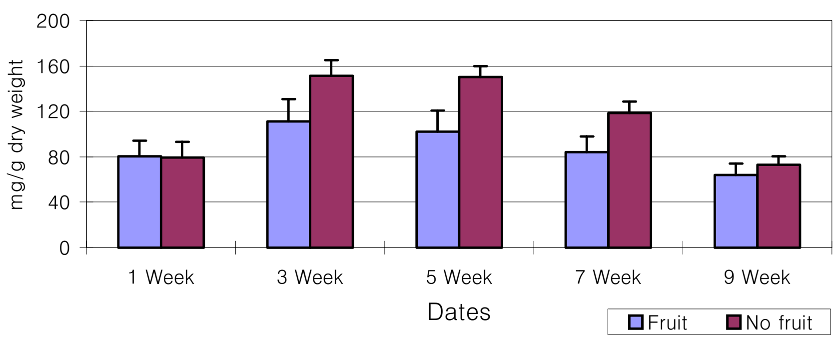

Fig. 6. Comparison of stachyose concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Raffinose. Raffinose was not detected at 1 week AA (Fig. 7). Small amounts of raffinose were found at 3 weeks AA. Raffinose increased up to 7 weeks AA, and then decreased at 9 weeks in plants with fruit (Fig. 7). In plants with the fruit removed, raffinose was first detected at 7 weeks AA and increased at 9 weeks

AA (Fig. 7). Significant differences in raffinose levels were observed among the dates and between the treatments (Table 2).

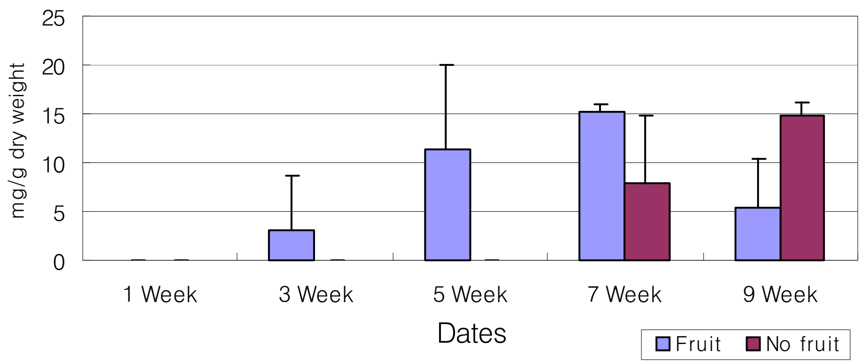

Fig. 7. Comparison of raffinose concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Sucrose. Sucrose accumulation in roots of plants with fruits removed fluctuated from 1 week AA to 9 weeks AA. Sucrose concentrations in roots of plants without fruit were the greatest at 7 weeks AA (28.12 mg/g dry root weight). Sucrose levels in the cantaloupe roots of plants with fruit increased at 3 weeks AA then decreased (Fig. 8). Significantly higher levels of sucrose were found in the roots of plants without fruit than in roots of plants with fruit, and there were significant differences among the sample dates (Table 2).

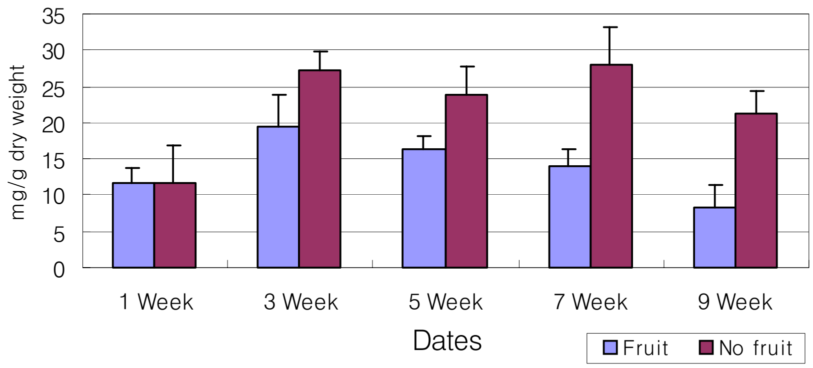

Fig. 8. Comparison of sucrose concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Glucose. Glucose concentrations in the cantaloupe roots generally reflected the stachyose pattern (Fig. 9). Glucose levels peaked at 3 weeks AA and then decreased regardless of treatment. In plants with fruit, glucose concentrations plateaued from 1 week to 5 weeks AA and then decreased dramatically at 7 (2.74 mg/g dry weight) and 9 weeks (0.36 mg/g dry weight) AA (Fig. 9). Significant differences in glucose concentrations were observed among the dates and between the treatments (Table 2), and were higher in roots from plants without fruit versus fruited plants.

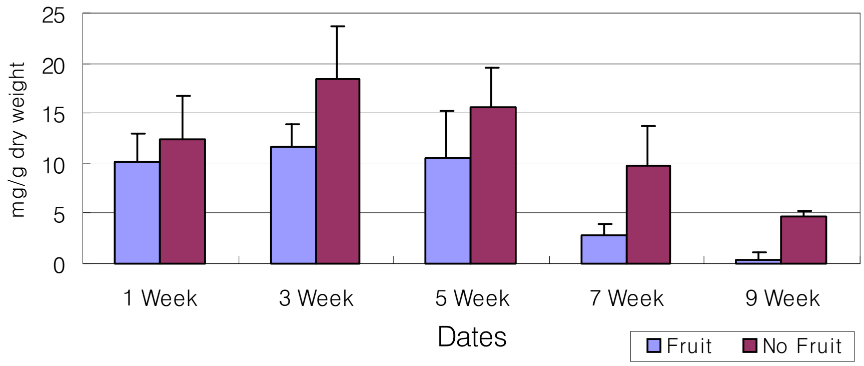

Fig. 9. Comparison of glucose concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Fructose. Fructose levels in the cantaloupe roots were similar to that of glucose (Fig. 10), and concentrations were similar to those of glucose (Fig. 5). At 1 week AA, fructose accumulation was not different between treatments, increased slightly up to 3 weeks AA, and then decreased. There were significant differences in fructose concentrations among the dates and between the treatments (Table 2).

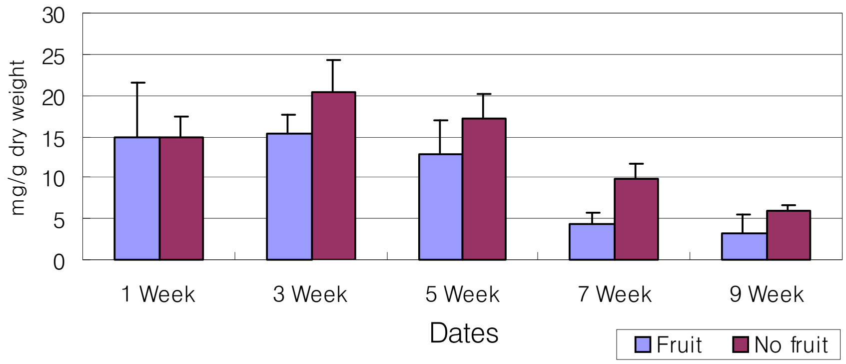

Fig. 10. Comparison of fructose concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Total sugar. Total sugar concentrations in the cantaloupe roots generally were similar to that of stachyose (Fig. 11). Total sugar levels peaked at 3 weeks AA (217.23 mg/g dry weight in plants with fruits removed, and 161.53/mg d dry weight in plants with fruit) and then decreased regardless of treatment. Total sugar concentrations were significantly higher in the cantaloupe roots from plants without fruit than in plants with fruit (Table 2).

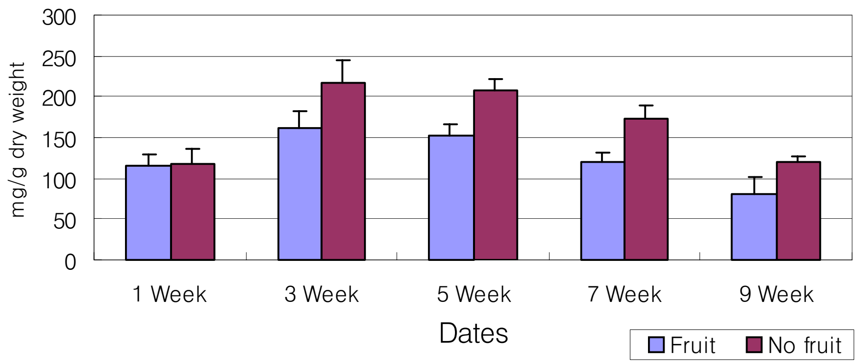

Fig. 11. Comparison of total sugar concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Sucrose, glucose, and fructose. Combined sucrose, glucose, and fructose concentrations in the cantaloupe roots with and without fruit had similar accumulation profiles to those observed for stachyose, glucose, and fructose (Fig. 12). Concentrations in the cantaloupe roots without and with fruit increased up to 3 weeks AA and then decreased. Overall the combined sugars in the cantaloupe roots without fruit were significantly higher than in roots with fruit (Table 2).

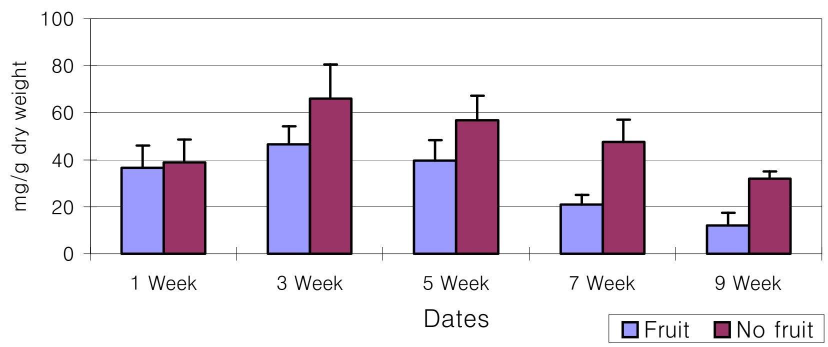

Fig. 12. Comparison of combined sucrose, glucose, and fructose concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Glucose and fructose. Combined glucose and fructose concentrations in the cantaloupe roots from plants with and without fruit were similar to the combined sucrose, glucose, and fructose patterns (Fig. 13). The combined sugars in plants with fruit decreased dramatically at 7 (6.99 mg/ g dry weight) and 9 weeks (3.63 mg/ g dry weight) AA. Total contents of glucose plus fructose in the cantaloupe roots from plants without fruit were significantly greater than in the roots from plants with fruit (Table 2).

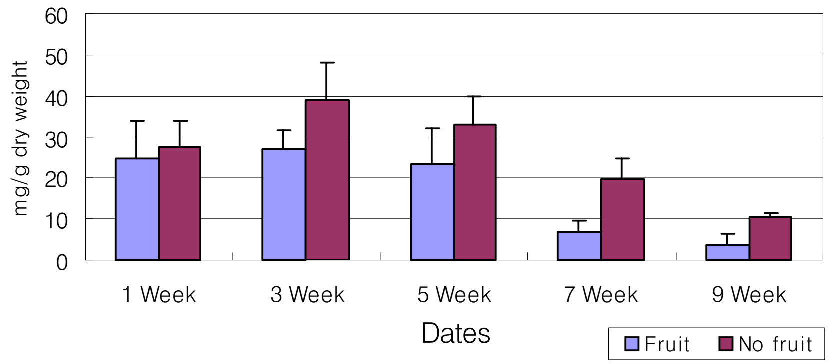

Fig. 13. Comparison of combined glucose and fructose concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Stachyose and raffinose. The pattern of combined stachyose and raffinose was similar to that of stachyose (Fig. 14). Combined stachyose and raffinose root sugars from plants with and without fruit resulted in significant content differences among the dates and between the treatments (Table 2). Stachyose and raffinose comprised 69 - 80 % and 67 - 75% of the total sugars in the cantaloupe roots from plants with and without fruit respectively (Fig. 5).

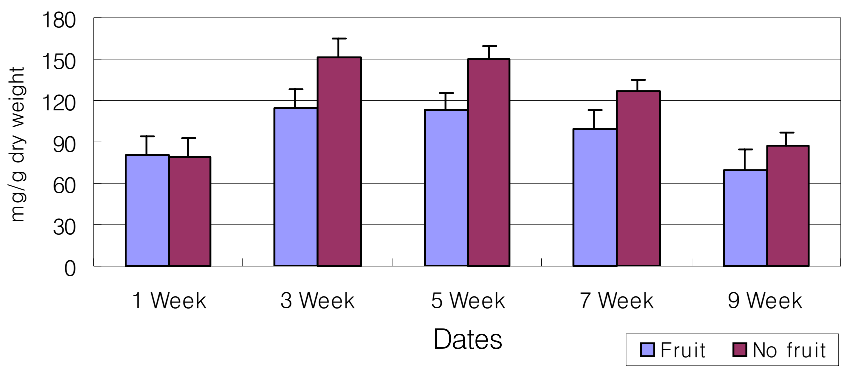

Fig. 14. Comparison of combined stachyose and raffinose concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Stachyose, raffinose and sucrose. The pattern of combined stachyose, raffinose, and sucrose was similar to that of stachyose (Fig. 15). Combined stachyose, raffinose, and sucrose concentrations peaked at 3 weeks AA and then decreased. Stachyose, raffinose, and sucrose comprised 78 - 95 % and 76 - 91% of the total sugars in the cantaloupe roots from plants with and without fruit respectively (Fig. 5). Combined stachyose, raffinose, and sucrose root sugars from plants with and without fruit resulted in significant content differences among the dates and between the treatments (Table 2).

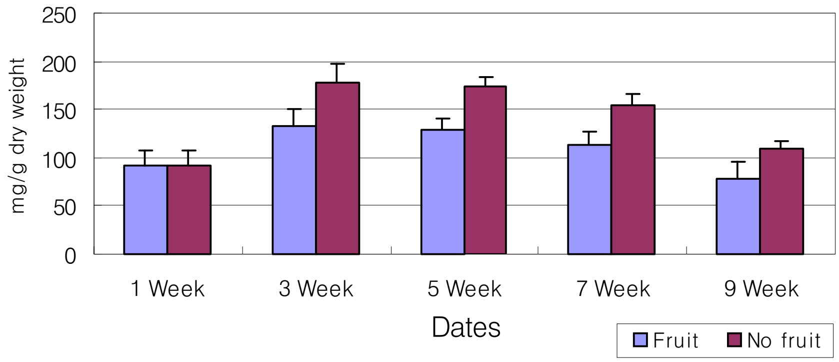

Fig. 15. Comparison of combined stachyose, raffinose, and sucrose concentrations in roots of plants with and without fruit from 1 week AA through 9 weeks AA (2003). Mean values represent six replications. Bars indicate standard error.

Disease severity in 2002 trial. Regardless of fruit removal treatments, disease severity on cantaloupe roots increased continuously from 4 weeks APD to 12 weeks APD. Few root rot lesions were observed at 4 weeks APD, but number of lesions gradually increased with time. The perithecia of *M. cannonballus* were present on the root surfaces of plants with fruit at 8 weeks APD. Disease severity ratings were less severe on roots of plants without fruit compared to roots of plants with fruit (Fig. 16). At 10 and 12 weeks APD, the majority of cantaloupe roots were severely infected with *M. cannonballus* independently, and numerous perithecia were found on roots of plants with fruit.

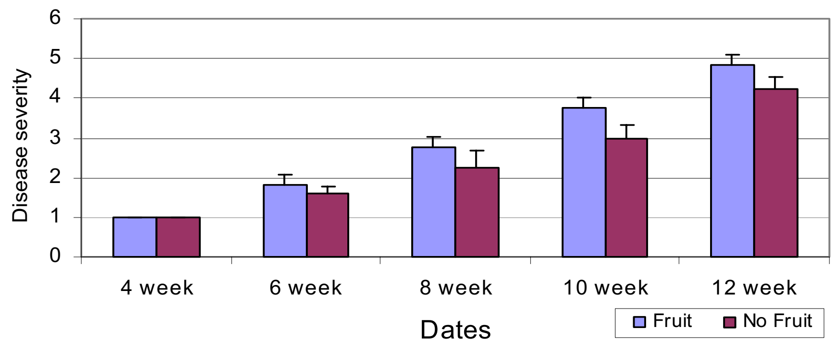

Fig. 16. Disease severity (2002) on the cantaloupe roots infected with *M. cannonballus*. A quantitative measure of disease severity was used a scale 1 to 5; 1 = No disease, 2 = root rot in secondary roots, 3 = root rot in main root and few perithecia present on roots, 4 = perithecia present in secondary roots, and 5 = severe root rot and perithecia present abundantly. Mean values represent six replications. Bars indicate mean standard error.

Root dry weights in 2002 trial. Root dry weight of cantaloupe increased with APD regardless of treatments (Fig. 17). Root dry weights for plants without fruit were higher than for plants with fruit. After 12 weeks APD, the maximum root dry weight (3.58g) for plants without fruit was attained.

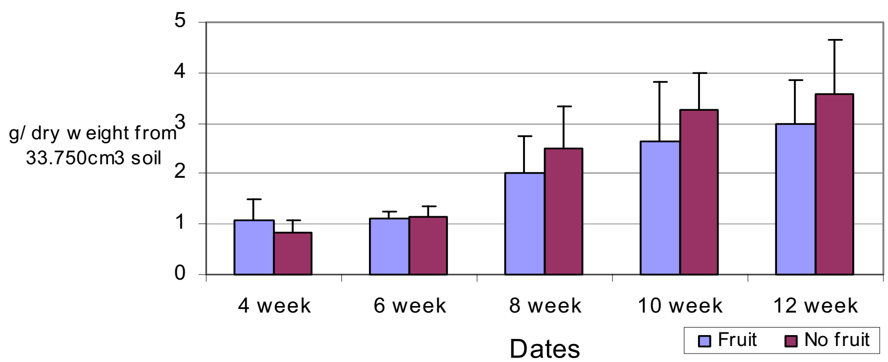

Fig. 17. Effect of fruit removal on dry weights of cantaloupe roots at 4 to 12 weeks APD (2002). Values are means of six replications with standard error indicated.

Carbohydrate concentration in cantaloupe roots in 2002 trial. Root sugar levels were higher plants without fruit than with fruit (Fig. 18), although not always significantly (Table 3). Five sugars including, stachyose, raffinose, sucrose, glucose, and fructose were found in the cantaloupe roots. Root sugars, sucrose, stachyose, and raffinose levels increased up to 8 weeks APD, and decreased, while glucose and fructose concentrations generally decreased through APD. Fruit removal resulted in root total carbohydrate levels to increase from 4 weeks APD to 8 weeks APD. After 8 weeks APD, total carbohydrate concentrations decreased regardless of treatment. Stachyose and raffinose comprised 63-78% and 66-74% of the total sugars in root from plant with and without fruit respectively.

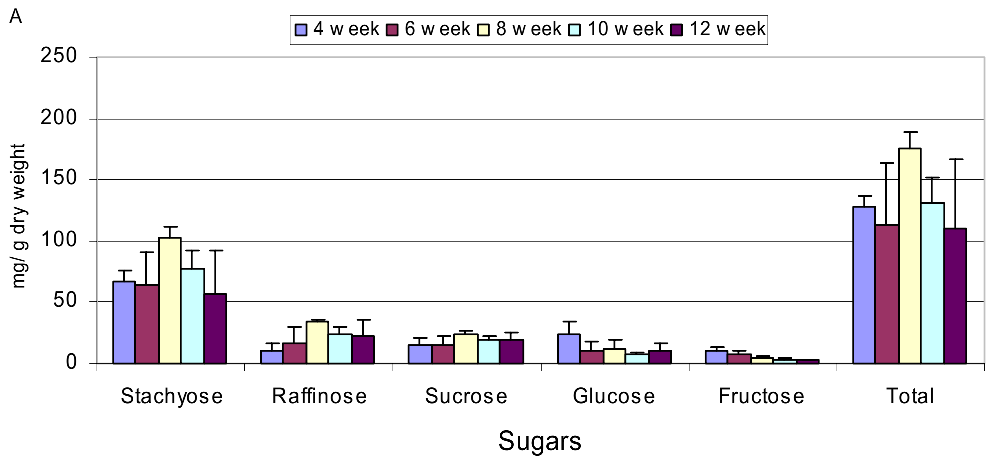

Fig. 18. Carbohydrate concentrations in roots of cantaloupe with fruit A) and fruit removed B) at 4 weeks APD through 12 weeks APD (2002). Values are means of six replications represent. Bars indicate standard error.

Table 3. Analysis of variance for effect of fruit removal on individual, total, and combined carbohydrate concentrations in cantaloupe roots (2002).

Source		Stachyose			Raffinose			Sucrose			Glucose			Fructose		
of data	DF	MS	F	P	MS	F	P	MS	F	P	MS	F	P	MS	F	P
Date(D)	4	3095.3	8.95	<.0001	1202.04	12.11	<.0001	298.47	12.23	<.0001	267.28	6.02	0.0005	85.5	22.79	<.0001
Treat(T)	1	375.05	1.08	0.3026	379.31	3.82	0.0562	88.86	3.64	0.0621	133.95	3.02	0.0885	16.53	4.41	0.0408
D*T	4	51.24	0.15	0.9629	37.84	0.38	0.8211	57.18	2.34	0.0674	117.36	2.64	0.0443	12.12	3.23	0.0196
Source		Total carbohydrates			Glucose+Fructose			Sucrose+Glucose+Fructose			Stachyose+Raffinose+Sucrose			Stachyose+Raffinose		
of data	DF	MS	F	P	MS	F	P	MS	F	P	MS	F	P	MS	F	P
Date(D)	4	9681.5	8.58	<.0001	614.51	10.27	<.0001	487.56	3.68	0.0106	9815.93	10.91	<.0001	7033.84	10.01	<.0001
Treat(T)	1	4084.41	3.62	0.0628	244.62	4.09	0.0485	628.36	4.74	0.0342	2329.89	2.59	0.1139	1508.71	2.15	0.1491
D*T	4	479.72	0.43	0.7897	200.5	3.35	0.0166	442.38	3.34	0.0169	146.01	0.16	0.9565	57.33	0.08	0.9877

CHAPTER IV

DISCUSSION AND CONCLUSIONS

Fruit removal resulted in greater sugar accumulation in the cantaloupe roots than in the roots from plants on which the fruits were allowed to develop normally. Individual, total, and combined root carbohydrate levels were greater in plants without fruit than in plants with fruit. Stachyose concentrations were higher than all the other sugars in the cantaloupe roots. Disease severity on the cantaloupe roots with fruit removed was less severe than on roots of plants with fruit. Root dry weights were higher in the fruit removal treatment than those of the fruit non-removal treatment. In 2003 trial, root sugar levels, disease severity, and root dry weights were significantly different between the treatments. Even though the data were not always significant for the 2002, root sugar levels and dry weights were higher in plants without fruit than in plants with fruit, and sugar accumulation pattern were the same trends with 2003.

Root sugar concentrations affected infection efficiency and disease progress of Monosporascus root rot and vine decline. Higher carbohydrate concentrations in roots without fruit of plants were associated with reduced root rot and perithecia on root surfaces compared to roots from plants with fruit across all sample dates. Thus, higher sugar accumulation in the cantaloupe roots appears to be inversely associated with disease development of Monosporascus root rot and vine decline. Carbohydrates are used for protection against environmental stress, and the roots act as a storage organ (16). Disease may reduce carbohydrate accumulation in diseased tissues and other organs (10), and significantly inhibit root system development in the soil (7). Normally, diseased plants have increased respiration and suppressed phothosynthesis compared to non-infected plants (18). Under these stress conditions, diseased plants exhibited modifications of carbohydrate translocation and an overall reduction. Thus, carbohydrate accumulation in the plants may affect in the development of disease progress.

Monosporascus root rot severity increased with root age, and perithecia were found on the root surfaces at 7 weeks AA in 2003 and 8 weeks APD in 2002 in plants with fruit. Similar results were reported by Stanghellini et al. (34). At this time, the cantaloupe roots were severely infected and symptoms of wilt appeared on the foliage. At 9 weeks AA, there were numerous perithecia on the root surfaces and severe root rot in plants with fruit. Although perithecia were present on the root surfaces in the fruit removal treatment at 9 weeks AA, the root systems of plants without fruit were not as severely infected and plants did not show wilting of the foliage.

Fruit removal affected the fresh and dry weights of the cantaloupe roots. The fresh and dry root weights increased up to 7 weeks AA regardless of treatment but decreased at 9 weeks AA in plants with fruit due to severe root rot. Root fresh and dry weights from plants with fruit removed were significantly higher than with the fruit attached; therefore, fruit removal affects root weights. These results are in agreement with those obtained by previous researchers (9,28). Compared to plants with fruit, plants whose fruit were removed showed higher carbohydrate concentrations, less disease severity, and higher fresh and dry root weights. Thus, the fruit removal treatment supported the hypothesis that disease progress for Monosporascus root rot and vine decline on the cantaloupe roots may be retarded due to greater carbohydrate accumulation and larger root systems.

Fruit removal resulted in an increase in the total number of healthy roots in cucumber and melon plants (30), and conversely fruit development decreased root growth. In cucumber plants, root dry weights were reduced with increasing number of fruits (20) and root growth was inhibited by fruit set (35). During the fruit set stage, most carbohydrates move from leaves to reproductive organs such as fruits, and vegetative growth is limited due to the lower supply of carbohydrates (36). Hurd et al. (15) also reported that flowering reduced root growth in tomato. Plants without fruit had a higher concentration of carbohydrates in the roots than in plants with fruit. In addition, the root systems of plants without fruit continued to grow, and dry weights of the roots were higher than in plants with the fruits (36). In this experiment, fruit removal also increased the root fresh and dry weights.

Fruit removal resulted in healthier and larger sizes of root systems in cucumber plants (30). The healthy root systems allow uptake of water and nutrients better than unhealthy roots (25, 36, 38). Well-developed root systems reduce potential water stress and allow the plants to have more vigorous vegetative growth (23). Accumulation rates of carbohydrates are influenced by restricted root volume (31). Reduced root volume of plants affects photosynthesis in leaves due to insufficient translocation of water and nutrients. Thus, root volume affects leaf photoassimilate levels and may regulate leaf areas and shoot weights in the plants.

Fruit removal allows plants to assimilate more carbohydrates and produce more vegetative growth (8). Carbohydrate and starch concentrations in leaves were higher in plants without fruits than those of plants with fruit (21). Fruit removal increased vegetative growth in the cucumber plants, and fruit growth was highly competitive with vegetative growth. The net carbohydrate assimilation rates of a vigorous cantaloupe will be higher than those of the less vigorous plant. Assimilates are uniformly transported from leaves to plant organs before fruit set, but more than 80% of assimilates are moved to the fruits after fruit set (36). Fruit removal should increase root growth and greater carbohydrate concentrations accumulated in the cantaloupe roots because the root will be a strong sink instead of the fruits. Otherwise, the heavier and bigger fruits would decrease root growth by reducing assimilates in the roots.

Five major carbohydrates (stachyose, raffinose, sucrose, glucose, and fructose) were found in the cantaloupe root. Individual and total sugar concentrations in the roots of plants with the fruit removed were significantly higher than in plants with fruit. Haritatos et al. (13) reported that stachyose, raffinose, and sucrose were the major transported sugars in cantaloupe. Stachyose, raffinose, and sucrose are found in the sieve element-intermediary cell complex. Low concentrations of galactinol were also found in the sieve element-intermediary cell complex. Stachyose, raffinose, and sucrose are transported from leaf cells to fruits and vegetative tissues such as stems, leaves, and roots in cantaloupe plants (5, 32, 33). Sucrose accumulates in the cantaloupe fruits, but stachyose and raffinose do not accumulate in the fruits (13, 26). Stachyose and raffinose are catabolized in peduncles and are converted to sucrose which accumulates in the fruits (11, 12). Stachyose and raffinose accounted for approximately 70% of the sugars in the fruit non-removal and removal cantaloupe roots. This indicates that both sugars are major transported sugars in the cantaloupe plants. These results are in agreement with studies of Handley et al. (12) and Schmitz et al. (33).

Stachyose and raffinose are the major transported sugars in woody plants (41), cucurbits (14, 39), and labiates (4). Stachyose acts as a storage sugar in roots and seeds (16). The accumulation of stachyose, raffinose, and sucrose in vegetative organs may provide protection against environmental stresses (2, 16). Soil flooding affects sugar concentrations of muskmelon plants (19). Plants grown in flooded soil have reduced levels of stachyose compared to concentrations of the non-flooded plants. In this study, results also showed that fruit removal increased stachyose concentrations in the cantaloupe roots and that these plants had decreased development of Monosporascus root rot and vine decline. Thus, high levels of stachyose accumulation in the cantaloupe roots may decrease development of disease.

This research tested whether carbohydrate partitioning into the cantaloupe roots may play a role in development of root rot and vine decline of cantaloupe caused by *M. cannonballus*. Fruit removal results in increased root growth and carbohydrate accumulation in the cantaloupe roots. These results affected development of Monosporascus root rot and vine decline. Therefore, the retarded development of Monosporascus root rot and vine decline is associated with a greater carbohydrate accumulation in the cantaloupe root.

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